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THE FIRST OPERATION OF NIMROD TO FULL ENERGY

For some time it had been planned that as soon as a reasonable vacuum had been achieved around the whole of the machine an attempt would be made to accelerate to full energy. This impatience was natural after six years of construction and it seemed wise to check for major faults as soon as possible. By August 5th the average pressure was a few times 10^{-6} mm of Mercury and still falling.

At this stage the following work had not been done:-

Commissioning of poleface winding corrections to the magnetic field (particularly gradient or n value and radial aperture)

Commissioning of the debuncher to reduce the energy spread from the injector

Installation of the low frequency ripple filter on the magnet power supply

Installation of the full set of diagnostic equipment required for detailed study of injection and acceleration

Operations started on August 6th, four runs being planned per week. The run up of various parts of the machine started during the afternoon whilst installation and other work continued. In the late afternoon the areas were locked and searched and operations began from the Injector Control Room. When the duty officer was satisfied about the security of the area and the state of readiness of the equipment, particularly the injector, he transferred himself and control to the Main Control Room. There he inserted an interlock key known as the "7 GeV key". Up till this point it is not possible to have in operation more than any two of the following: magnet power supply, injector, synchrotron R.F.

The following diagnostic equipment was available:-

A rectractable scintillator with T.V. camera to view the beam in Octant 1 immediately after the inflector.

Retractable fluorescent grids with T.V. cameras. The grids cover the full aperture and have a transmission factor of 97 to 98%. One grid per Octant.

A directive scintillator probe on the inside of the aperture at Octant 6. Viewed by a photomultiplier through a flexible light guide. Oscilloscope presentation.

Induction electrodes in Straight 6 with oscilloscope presentation of sum signal (beam current) and difference signal (radial position).

Various counter set-ups looking at "spill" from the machine.

The following diary of events is abstracted from the Log Book.

First Week

August 6th Tuesday * First Turn	First injection into the complete machine. Peak field 9120 gauss with the correspondingly reduced rate of rise of field ($\dot{B}$) without using the "injection platform" to reduce initial rate of rise. Injected pulse length 50 μs. Beam seen immediately on grids 5 and 6 (Octants 5 and 6) and improved by steering. Dubious evidence of second turn on grid 5. Induction electrodes with D.C. connection showing mainly charge collection.

August 7th Wednesday	Peak field 14,000 gauss. Injection platform would not work. Changed to 90% volts, 14.6 kilogauss, 18 kg/sec. Definite signal at Octant 6 photomultiplier showing circulation for 100 μs with 50 μs pulse going in. Acceleration tried with no success.
August 8th Thursday	100% magnet volts; no injection platform; 20 kg/sec. Alignment on grids as before. Grid pictures gave an idea that Q vertical was near to 1, hence Q* radial near to ½. Chopper used to give 0.25 μs pulse. Second turn seen after A.C. connection of induction electrodes. Power supply trouble.
August 9th Friday	Magnet volts 100%. 1.1 μs chopped beam. Survival for 20 turns seen on induction electrodes. Difference electrodes showed Q radial near to ½. At 10 kg/sec only 3 very weak turns observed.

Second Week

August 10th Tuesday	Decided to try for 7 GeV with 20 kg/sec. With several turns survival R.F. was tried without any sign of acceleration. Discovered at end of run that grids 2 and 4 were still in.
August 14th Wednesday * First acceleration	40 turns. Grids 2 and 4 probably stayed in on all previous runs. Difference electrodes indicated Q radial about 0.53. The inside probe showed something like the energy spread of the injector on alternate pulses. This also indicated Q radial about 0.5. R.F. tried with signs of R.F. trapping. After critical setting of initial conditions survival was seen to 7 ms. on the induction electrodes. Spill seemed to be observable on counter to 12-15 ms with a vague indication of the occasional pulse to 50 ms.
August 15th Thursday	n shift of .07 was available, also some aperture correction windings, all for low fields. None of the corrections did any obvious good and generally things got worse. R.F. was tried but the acceleration time was no better. A power supply on the poleface windings was burnt out.
August 16th Friday	The field corrections all self-powered. The evidence from survival of a short pulse was that the corrections were the wrong way round.

Third Week

August 20th Tuesday	Poleface windings now connected correctly. No survival could be obtained with n shift on all octants, but with correction on Octants 6 and 7 only there was a marked improvement. This was consistent with the higher average n in these two octants from field survey. After the usual loss in the first turn the amplitude hardly changed until signal began on the inside probe. The aperture winding increased the injection period from 225 μs to 260 μs. In all the number of surviving turns went up from 40 to 57 and there were at last signs of particles with small amplitude betatron oscillations.
August 21st Wednesday	Good amplitude and survival of short pulses was obtained. Q radial now in the range 0.58 to 0.6 instead of 0.53 to

* Q is the number of betatron oscillations per revolution.

0.56 as without poleface windings. Many faults closed down the run.

<u>August 22nd</u>
Thursday

Good starting conditions. R.F. on and acceleration to 16 ms. Sum and difference induction electrode signals showed beam to be going inwards at 5 ms.

<u>August 23rd</u>
Friday

Inflector moved in 1". Better injection but pulse to pulse reproduceability very bad. R.F. survival to 40 ms with strange "resonances" and a sudden cut-off.

<u>Fourth Week</u>

<u>August 26th</u>
Monday

Injection improved markedly with a very critical adjustment of the inflector voltage. Acceleration to 65 ms after working with R.F. frequency law curve-corrector. "Resonances" on induction electrodes are obviously not beam blow-up. They are either resonances of the electrodes and/or beam spill on to the electrodes. Things looking more hopeful.

<u>August 27th</u>
Tuesday
Morning start up
*6.5 GeV to 8 GeV

Amplitude and survival of short pulse the best so far. After R.F. curve correction acceleration was obtained to 230 ms. Beam would not survive beyond this point which is on the knee of the frequency curve, and loss occurred to the outside of the aperture. The shaper coil in the tank circuit of the P.F.G. was changed from 1.17 μH to 1.72 μH to give a shallower knee. Further work with the curve corrector took the beam all the way to 6.5 GeV corresponding to the peak field being used. The intensity was about 4 x 10^9 protons/pulse.

The peak field was increased in small steps and rough optimisation was carried out by varying initial $\dot{B}$. A small number of pulses was tried at 15.9 kilogauss and 8 GeV was observed with about 10^9 protons/pulse. There did not appear to be any appreciable loss from 6.5 to 8 GeV. The run continued at 7 GeV and the highest intensity achieved was 10^{10} protons/pulse.

17.20 hours	6.5 GeV
18.30 hours	8.0 GeV
19.00 hours	7 GeV, 10^{10} protons/pulse

The "corrected" frequency law was substantially below that which we started with until beyond the knee of the curve, and there were considerable bumps. The deviation corresponded to something like an error in stable orbit of one metre. The bumps were later ironed out.

The drama was intense for those who were actively engaged and for the many others who visited us and encouraged us until the early hours of the morning. It must be admitted that the high energy physicists "got there first". The operator of the frequency-curve corrector was so concentrating on pushing the beam further and further along his oscilloscope trace that he didn't have his zero set and didn't realise immediately that he had got to the end. It must also be admitted that three key experimenters misjudged the time to take their evening meal and the news had to be brought to the restaurant by runner. That night we closed down some three to four hours earlier than usual for a minor celebration, but not before we had telephoned the good news to Lord Bridges, the Director and others. The following day saw the Laboratory full of smiling faces. We had the proud and happy task of sending telegrams around the world and the pleasure of receiving a tremendous number of most complimentary replies.

This first full performance of the machine was better than we could have hoped for at so early a time and with so many things still to be done. To have 10^{10} protons/pulse at 7 GeV was extremely pleasing since we knew that without the magnetic field corrections injection was poor, and in any case with the full rate of rise of magnetic field the injection time was short. The measurement of current is a tricky business but we believe our figures to be conservative. The way seems to clear for achieving an output between 10^{11} and 10^{12} protons/pulse. To go on to 8 GeV without any high field correction and with no appreciable loss of beam was quite a surprise. With a bigger and better beam at injection the beam is likely to be bigger at full energy, so that correction may then be necessary to obtain a sufficient "good field" region.

Apart from the known deficiencies there did not appear to be any major design or construction fault. The vacuum system behaved well and the average pressure was about 10^{-6} mm of mercury with one of the gauges reading just below 10^{-7} and the speed of pump-down was high. The first pump-down of the whole vacuum vessel started on August 1st and the pressure was down to 6×10^{-6} on August 3rd. Later pump-downs were much faster and after a complete power failure which resulted in the pressure being equalised between the inner and outer vessels at about 0.1 mm of mercury the pressure was sufficiently low for operation some two hours later. This leads us to believe that we have a reasonable factor in hand to deal with outgassing and leaks resulting from the introduction of targets and other experimental apparatus. The reliability of the major parts of the machine was at least as good as could be expected. Most of the faults, although admittedly time consuming and annoying, were minor things such as interlock and cable faults and failures of water cooling.

A 7 GeV beam has been run on several occasions since, in particular for a radiation survey. Some work was done on slower rate of rise of field at injection and an output of 2×10^{10} was recorded. We were about to suspend acceleration to 7 GeV for a period of some three or four weeks to "commission" the poleface windings and work on injection conditions whilst having little other disturbance of the machine. Unfortunately some suspected breakdown occurred in one of the eight transformers between the alternators and the rectifier groups. Whilst this trouble was being investigated the programme was switched to carrying out essential installation, including some beam ports and target mechanisms. No conclusive information could be obtained from a wide range of tests on the transformer so that, by elimination, the fault appeared to be inter-turn breakdown in the primary or secondary. The transformer had to be put back into service to check this theory, and within a very short time the evidence of an inter-turn short on the primary developing to include a short to the core was quite obvious. The transformer started on its way back to the manufacturers in Scotland to be rewound on 16th September. Despite the best efforts of all concerned we are most unlikely to have it back in service in less than a month, and six weeks would not be unexpected. At the same time the transformer will be checked for design or constructional faults which might result in further breakdown in this transformer and the others. We are fortunate in having a power supply in symmetrical halves. The commissioning of poleface windings is being carried out with half the power supply feeding halves of the magnet in succession. Further work with the poleface windings and injection studies with reduced rate of rise of field can be done with half the power supply feeding the whole of the magnet. Trapping and acceleration studies can also go on in this fashion. The time will not be wasted and indeed the delay to programme will not be as serious as it might appear.

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